Training School for Young Researcher

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Fire Safety Engineering for open and closed car parks: C.A.S.E. Project for L'Aquila

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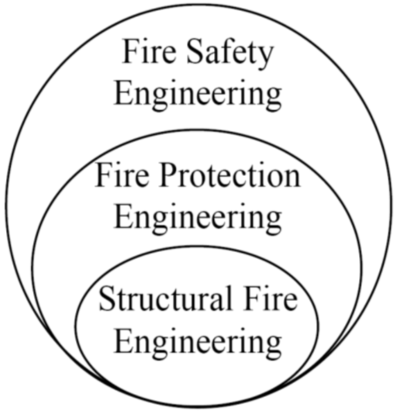
Introduction: Fire Safety Engineering



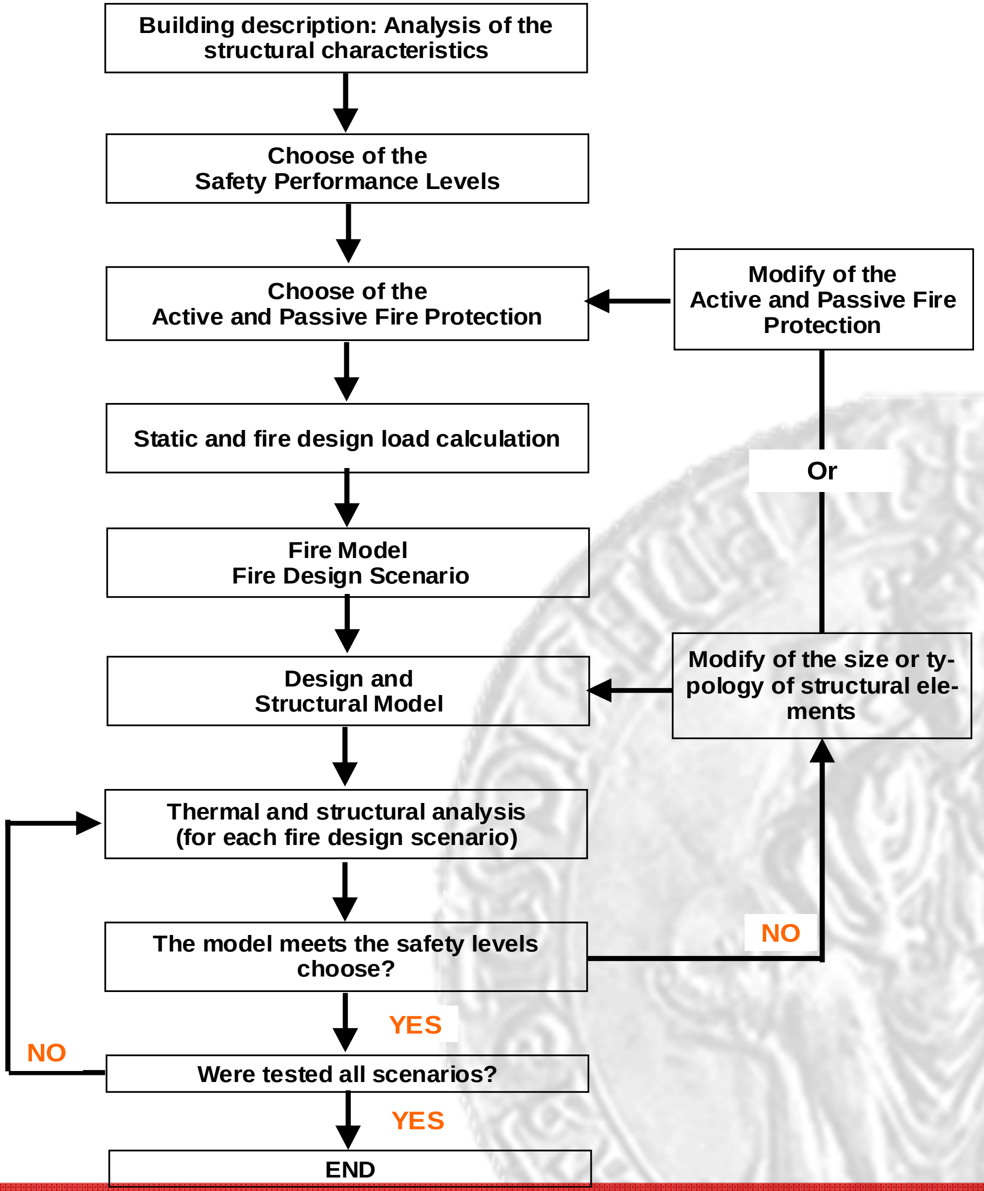
The "Fire Safety Engineering" (FSE) is the application of engineering principles, rules and expert judgement based on a scientific assessment of the fire phenomena, the effects of fire and both the reaction and behaviour of peoples, in order to:

- **save life, protect property and preserve the environment and heritage,**
- **quantify the hazards and risks of fire and its effects,**
- **evaluate analytically the optimum protective and prevention measures necessary to limit, within prescribed levels, the consequences of fire (ISO/TR 13387-1).**

A branch of Fire Safety Engineering is Structural Fire Engineering.

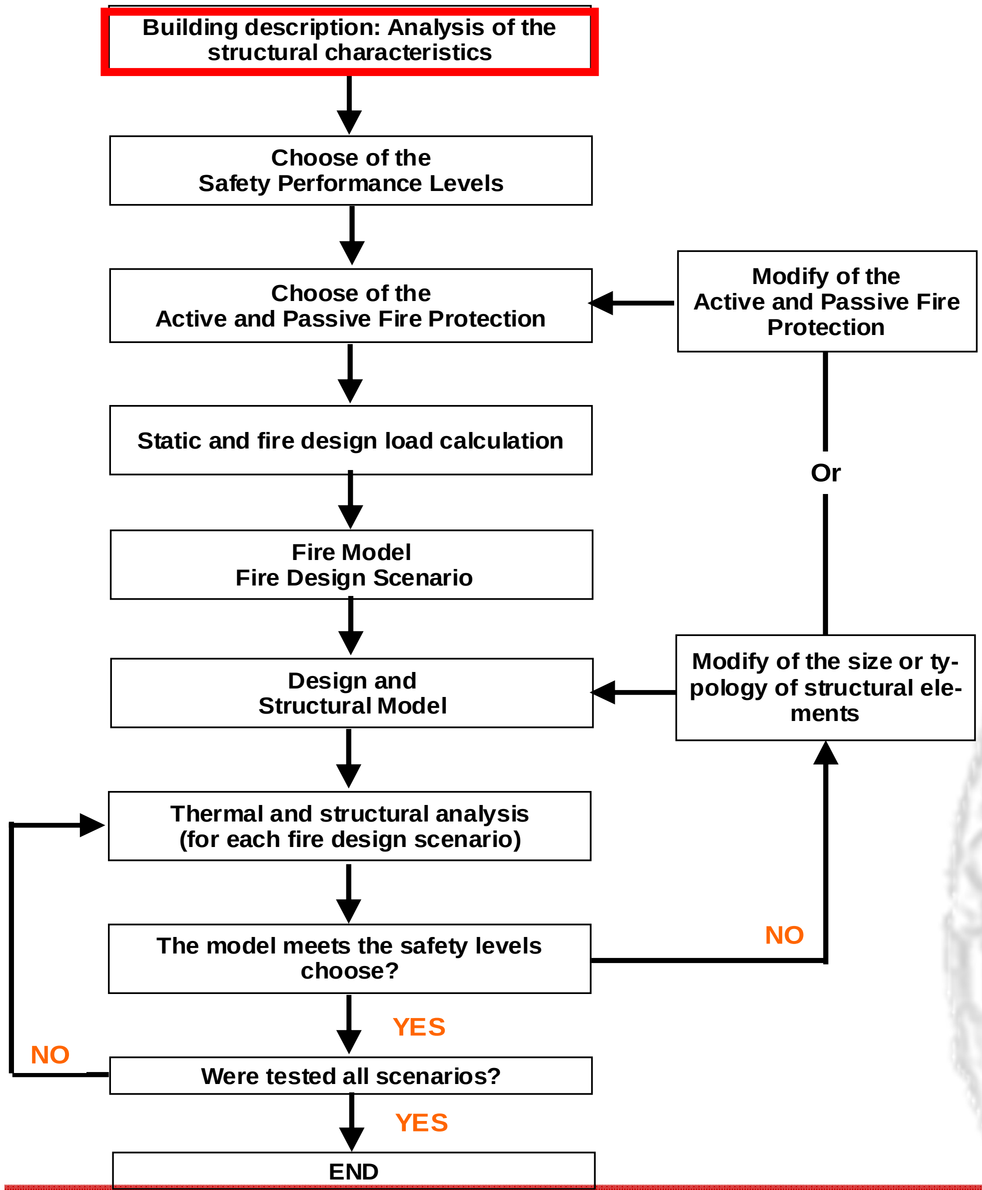
Structural Fire Engineering deals with specific aspects of passive fire protection in terms of analysing the thermal effects of fires on buildings and designing members for adequate load bearing resistance and to control the spread of fire (C. Bailey).

FSE: Layout



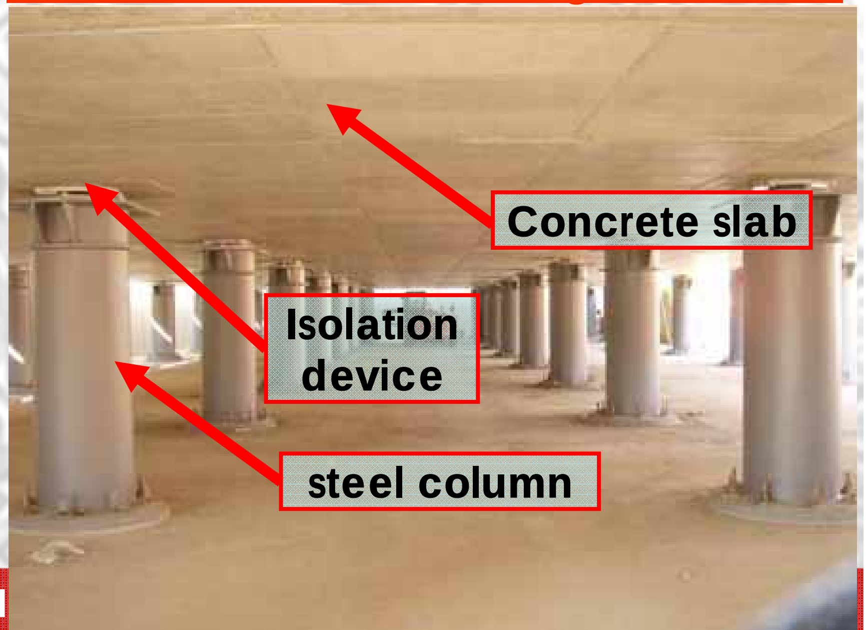
Building description: Analysis of the structural characteristics
Choose of the Safety Performance Levels
Choose of the Active and Passive Fire Protection
Modify of the Active and Passive Fire Protection
Or
Static and fire design load calculation
Fire Model Fire Design Scenario
Design and Structural Model
Modify of the size or typology of structural elements
Thermal and structural analysis (for each fire design scenario)
The model meets the safety levels choose?
NO
YES
NO
Were tested all scenarios?
YES
END

Case Study: Car Parks of C.A.S.E. Project for L'Aquila

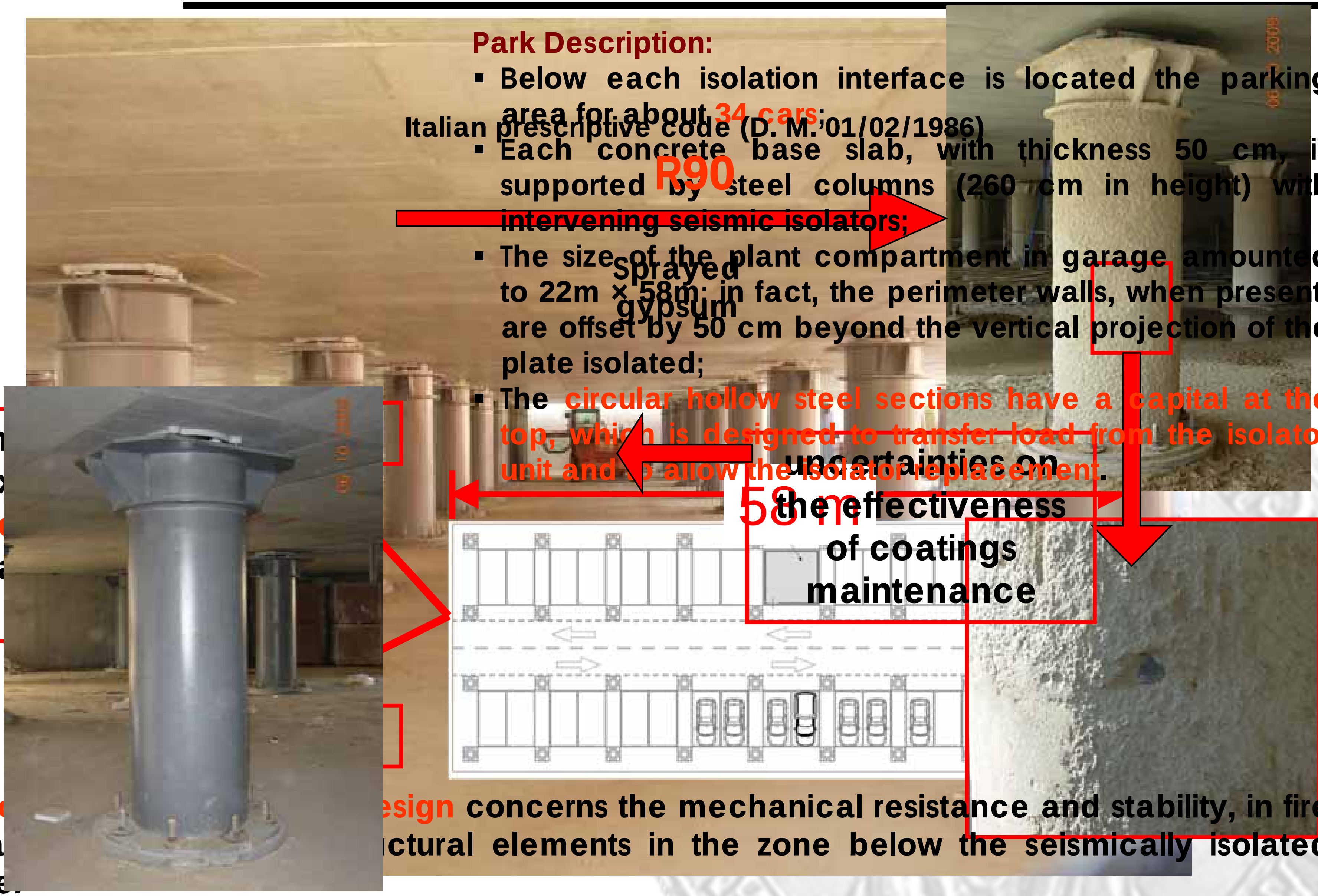


The "**C.A.S.E. Project for L'Aquila**" was developed in L'Aquila (province of Abruzzo, Italy), after the seismic event of 06/04/2009, in response to the housing emergency. It was characterised by the construction of several **seismically isolated buildings**.

Car Park located at the ground floor



Case Study: Car Parks of C.A.S.E. Project for L’Aquila



Park Description:

- Below each isolation interface is located the parking area for about 34 cars;
- Each concrete base slab, with thickness 50 cm, is supported by steel columns (260 cm in height) with intervening seismic isolators;
- The size of the plant compartment in garage amounted to 22m × 58m; in fact, the perimeter walls, when present, are offset by 50 cm beyond the vertical projection of the plate isolated;
- The circular hollow steel sections have a capital at the top, which is designed to transfer load from the isolator unit and to allow the isolator replacement.

Italian prescriptive code (D. M. 01/02/1986)

R90

Sprayed gypsum

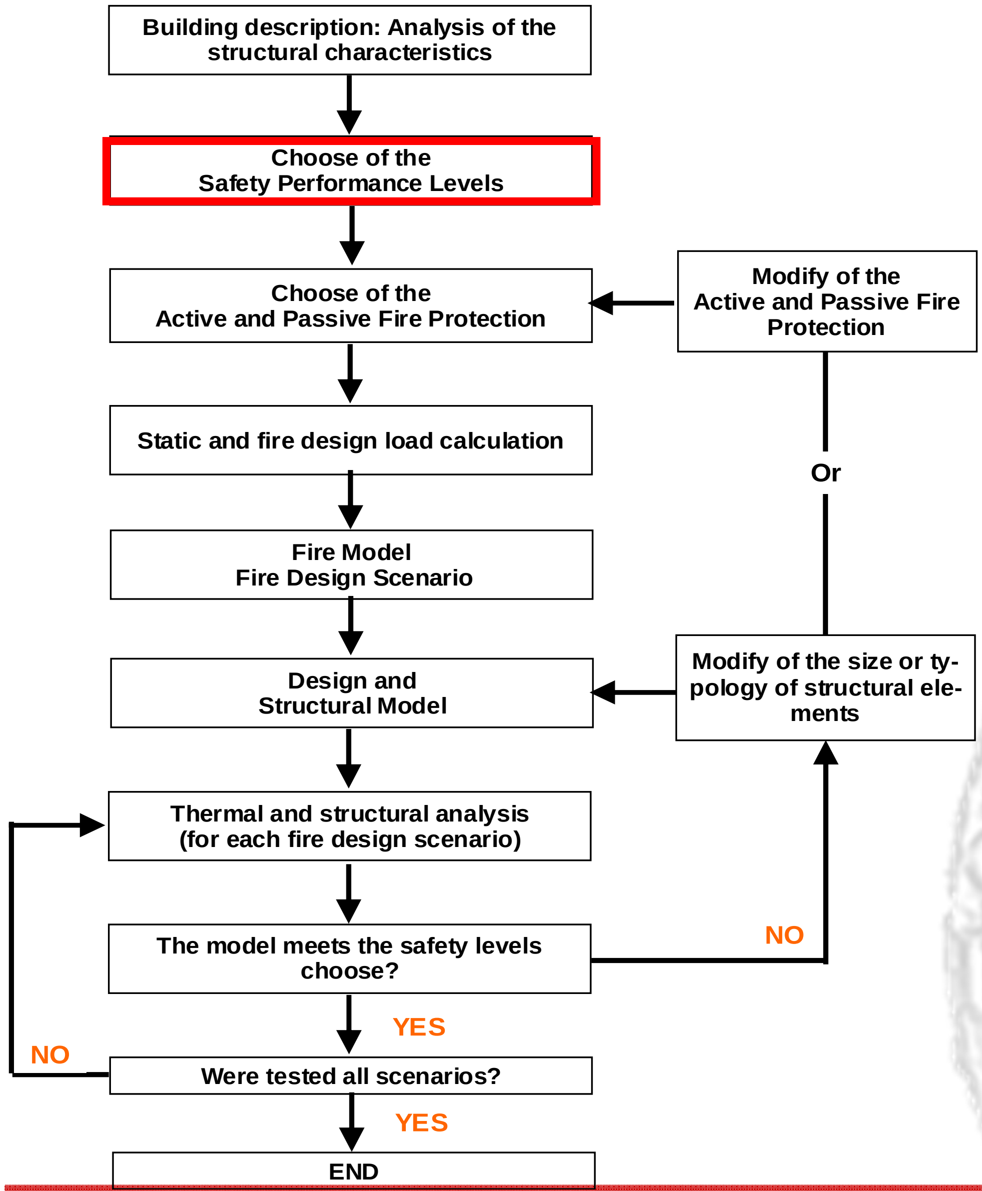
Th
ex
eva

58 m

uncertainties on the effectiveness of coatings maintenance

The ... esign concerns the mechanical resistance and stability, in fire situa... ctural elements in the zone below the seismically isolated plate.

Case Study: Car Parks of C.A.S.E. Project for L'Aquila

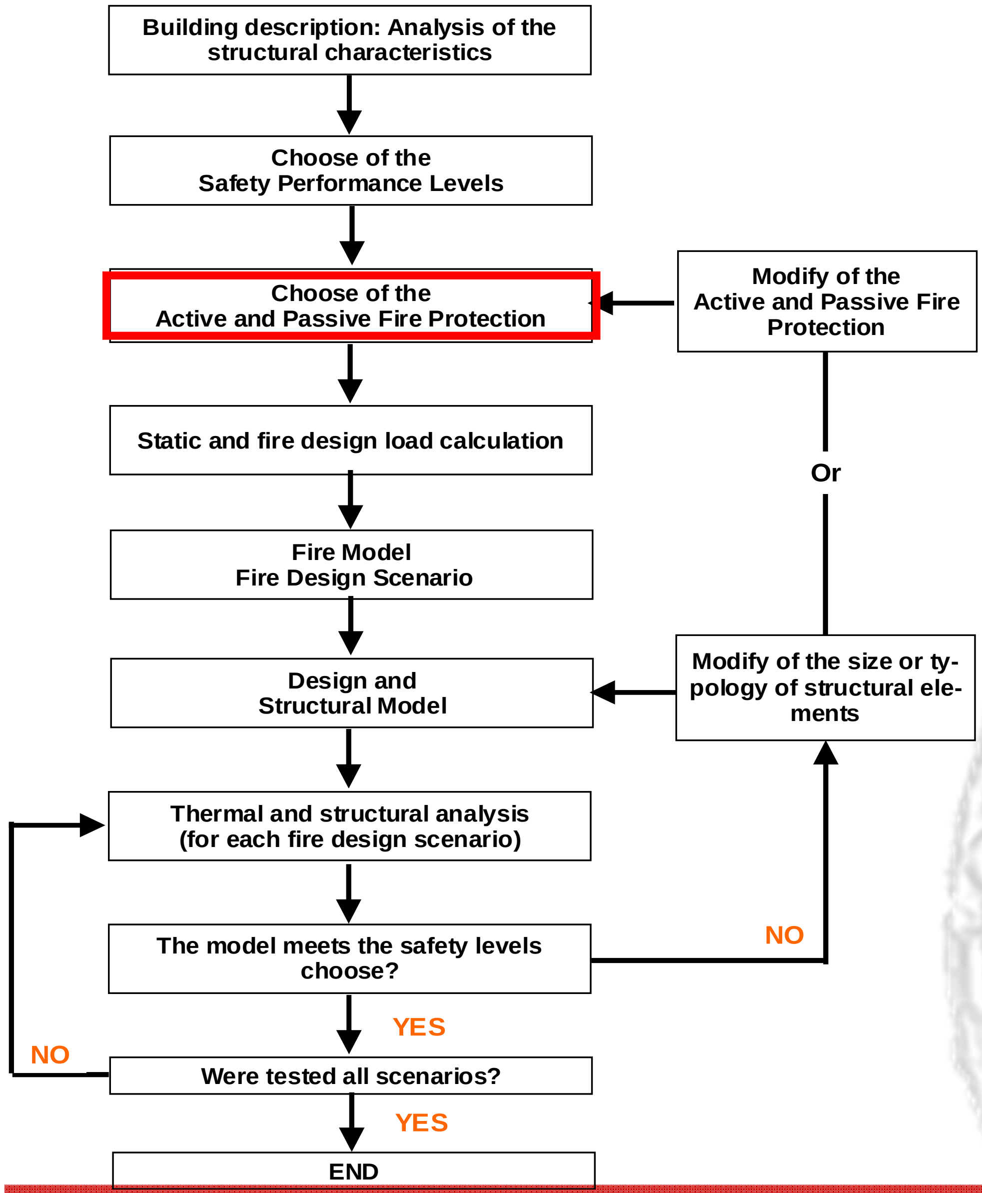


Performace level

A limited damage after the fire exposure.

The damage is quantified in terms of relative vertical displacements between the top of two adjacent columns: in order to limit the finishing damage in the superstructure, the relative vertical displacement must not exceed the limit value, chosen cautiously equals to L/200 (5.0 ‰), where L is the distance between two adjacent columns (L=6000mm).

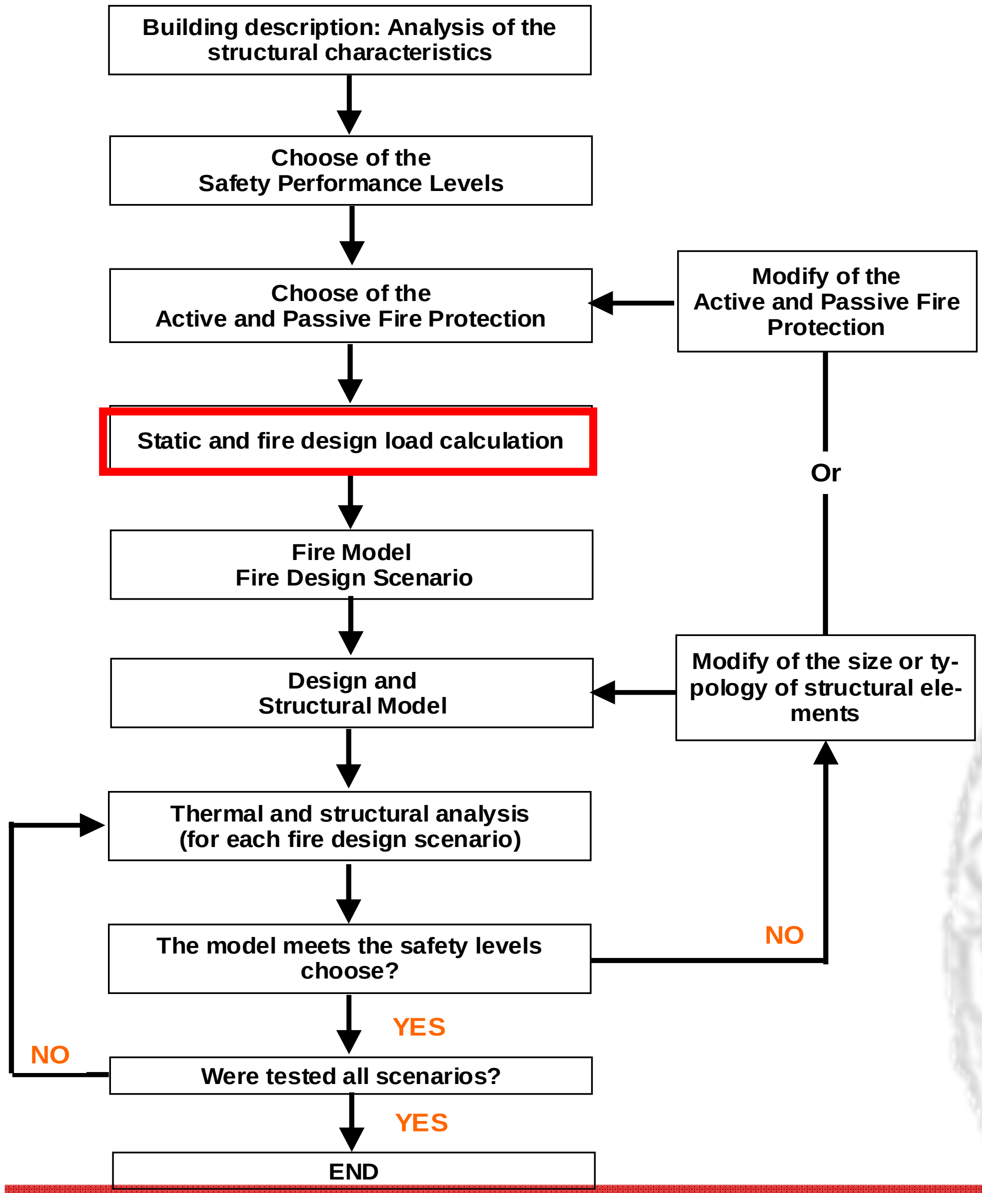
Case Study: Car Parks of C.A.S.E. Project for L'Aquila



Protection systems

No specific protection systems (active and/or passive) are provided.

Case Study: Car Parks of C.A.S.E. Project for L'Aquila

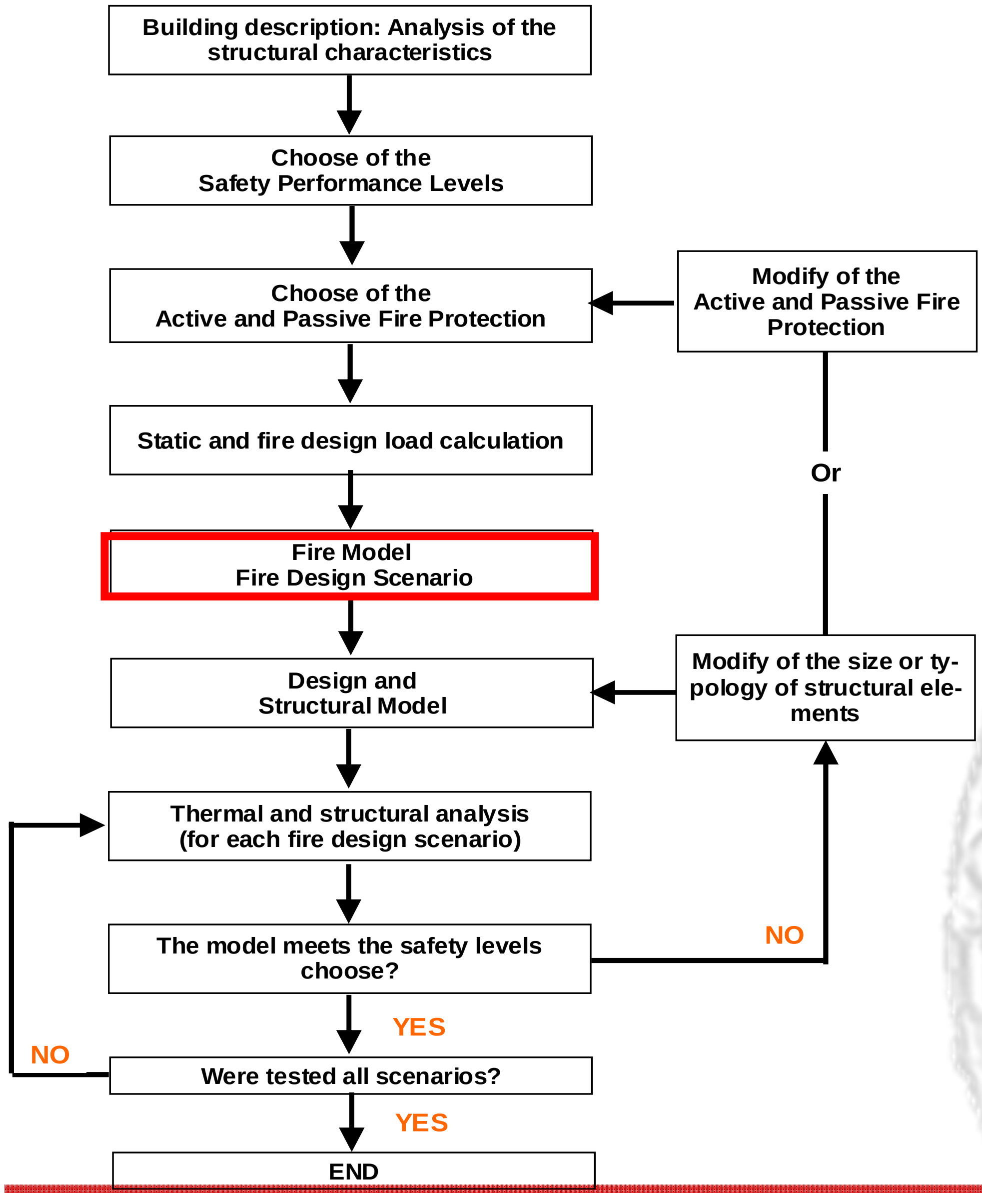


Fire design load combination

$$F_d = A_d + G_{k1} + G_{k2} + \sum_{i=1}^{n} \psi_{2i} \cdot Q_{ki}$$

Combinations of actions for accidental design situations

Case Study: Car Parks of C.A.S.E. Project for L’Aquila



Fire Scenario

qualitative description of the course of a fire with time identifying key events that characterise the fire and differentiate it from other possible fires. It typically defines the ignition and fire growth process, the fully developed stage, decay stage together with the building environment and systems that will impact on the course of the fire (EN1991-1-2)

Case Study: Car Parks of C.A.S.E. Project for L'Aquila

The fire scenario is significantly affected, among other things, by:
- the geometry and
- ventilation conditions of the compartment.
As regards the evaluation of number of vehicles involved in the fire and the timing of fire initiation by a car to adjacent one, reference is made to the information provided by following Technical References and Guideline.

Technical References and Guideline

CEC Agreement 7215 - PP/025: "Demonstration of Real Fire Tests in Car Parks and High Buildings", by CITCM (France), PROFIL-ARBED Recherches (Luxembourg) e TNO (Netherlands), closed 2001

INERIS Guideline: "Parcs de stationnement en superstructure largement ventiles. Avis d'expert sur les scénarios d'incendie", Final Report 2001 by INERIS (Institut National de l'Environnement Industriel et des Risques) and by CTICM (Centre Technique Industriel de la Construction Metallique).

REPORT PARCHEGGI (REPORT ON ITALIAN CAR PARKS): *"Approccio ingegneristico per la sicurezza strutturale in caso di incendio di parcheggi aerati realizzati con struttura di acciaio"*, Rapporto Interno Finale del 2010. Commissione per la Sicurezza delle Costruzioni di Acciaio in caso di Incendio.

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Case Study: Fire Scenarios - Open Car Parks

Open Car Parks

CEC Agreement 7215 - PP/025:

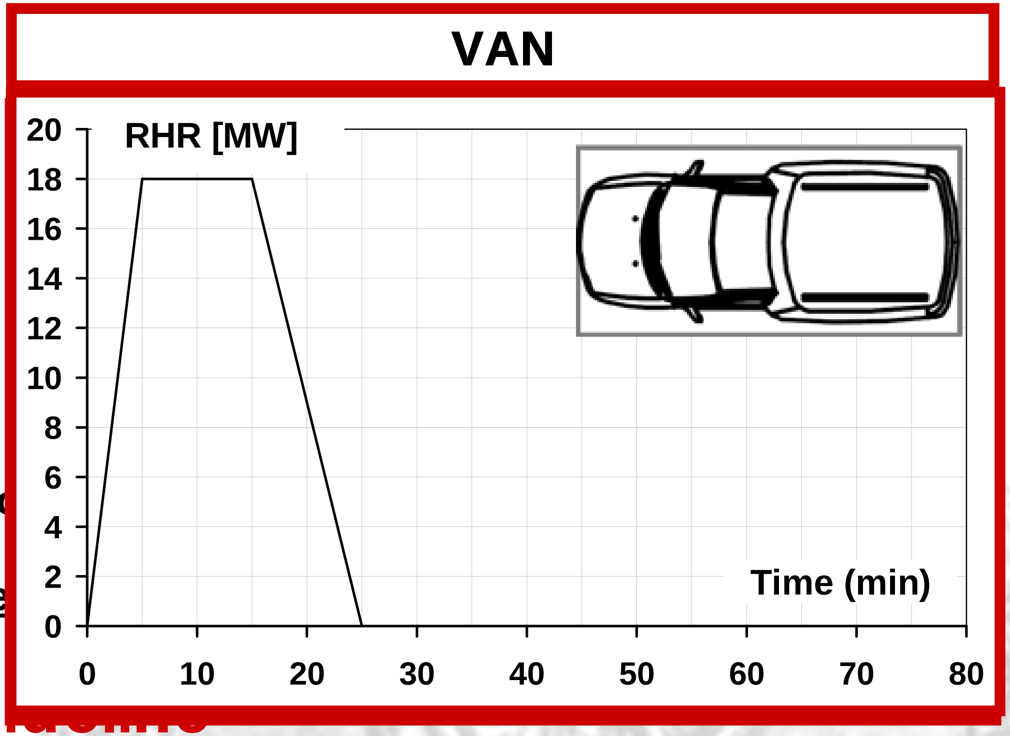
The research consisted in:

✓**Calorimetric Hood tests.**

✓ **Full-scale tests**

➢l

➢**fire**



INERIS Gu

Location and number of cars involved in fire

Case Study: Fire Scenarios - Closed Car Parks

Closed Car Parks

CEC Agreement 7215 - PP/025:

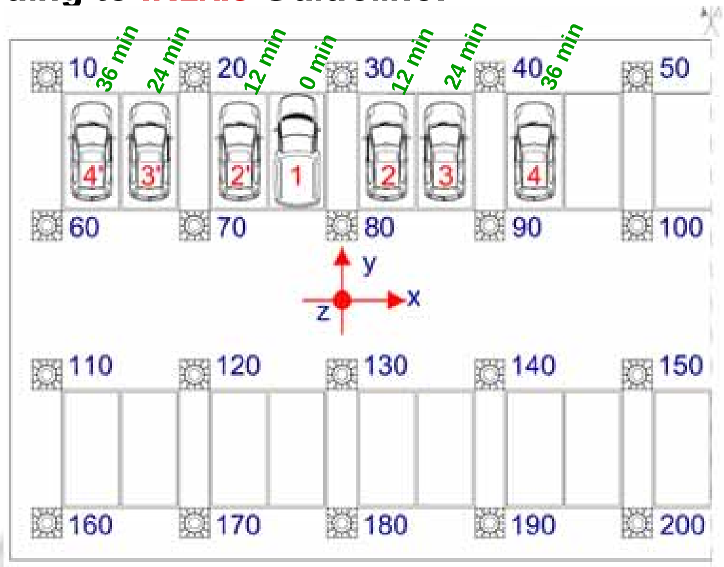
✓ **Full-scale tests** →

Results

➢**“pre-flashover” fire and post-flashover“ fire;**
➢**fire propagation times by a car to adjacent one is about 6 min**

Case Study: Design Fire Scenarios

✓ **Localised Fire Scenarios - Pre-flashover** according to **INERIS** Guideline.

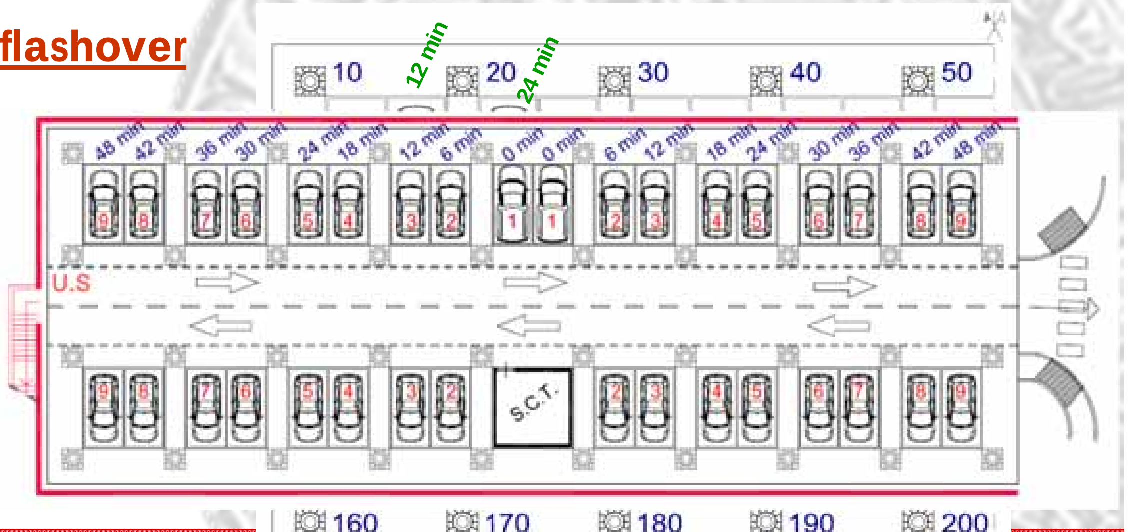


SCENARIO L1: **7 vehicles, of which 1 central VAN and 6 cars, that burn with a fire propagation time from car to adjacent one equals to 12 min from the VAN.**

SCENARIO L2: **4 vehicles, of which 1 central VAN and 3 cars surrounding a column, that burn with a fire propagation time from car to adjacent one equals to 12 min from the VAN.**

Propagation time 12min.

✓ **Generalized Fire Scenario- Post-flashover**



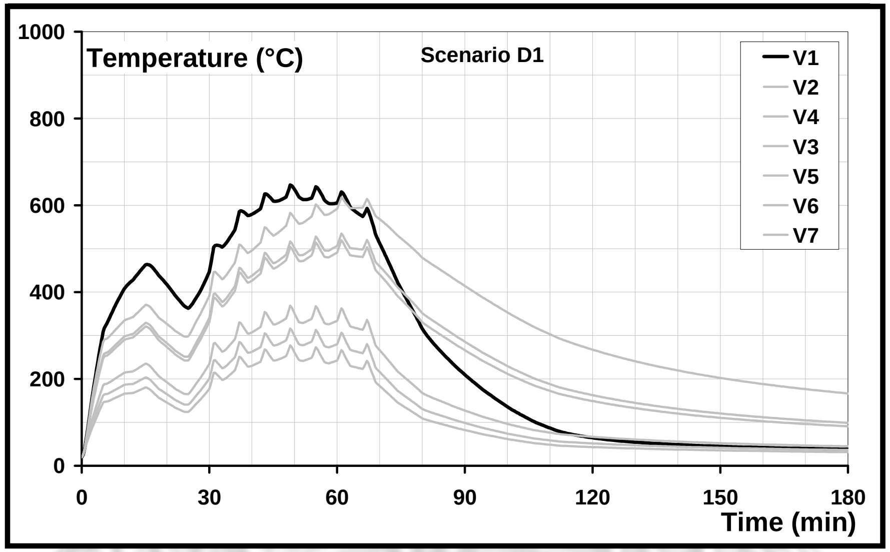
SCENARIO D1: **34 vehicles, of which 2 central VAN and 32 cars, that burn with a fire propagation time from car to adjacent one equals to 6 min from the VAN**

Propagation time 6 min.

Case Study: Fire models

➢Generalized Fire Scenario

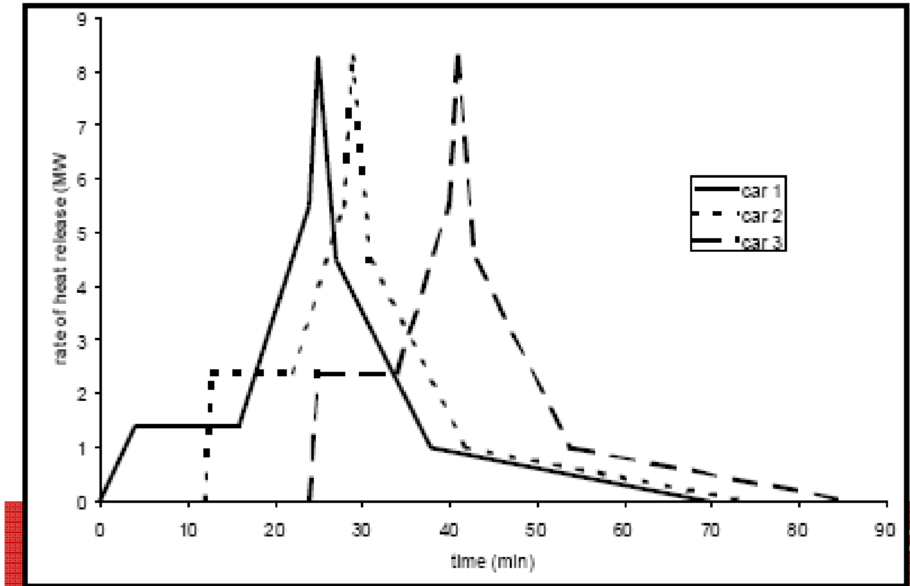
One-Zone Model
[Annex D, EN1991-1-2]



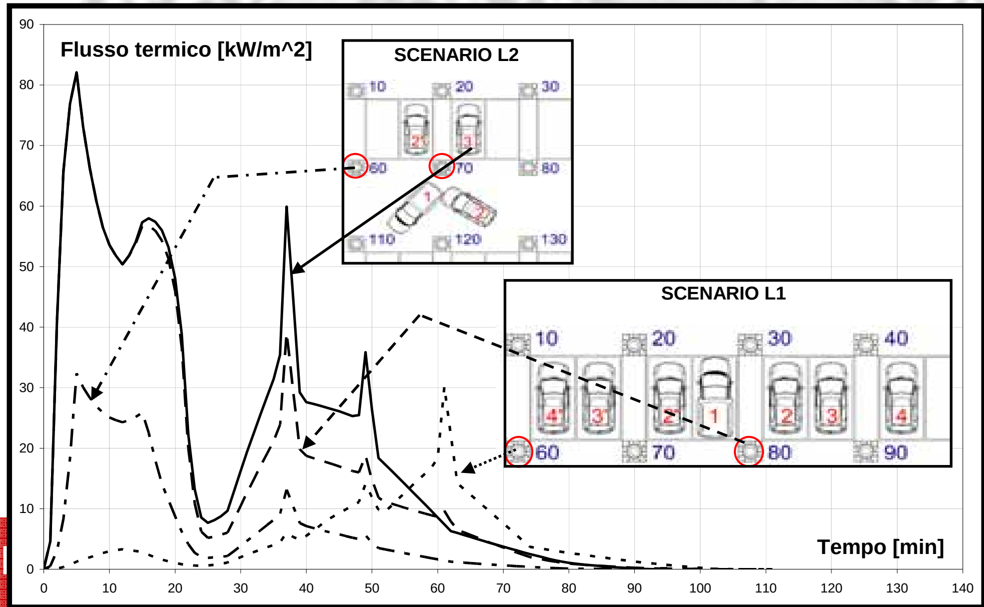
➢Localised Fire Scenarios

Hasemi's Method
[Annex C, EN1991-1-2]]

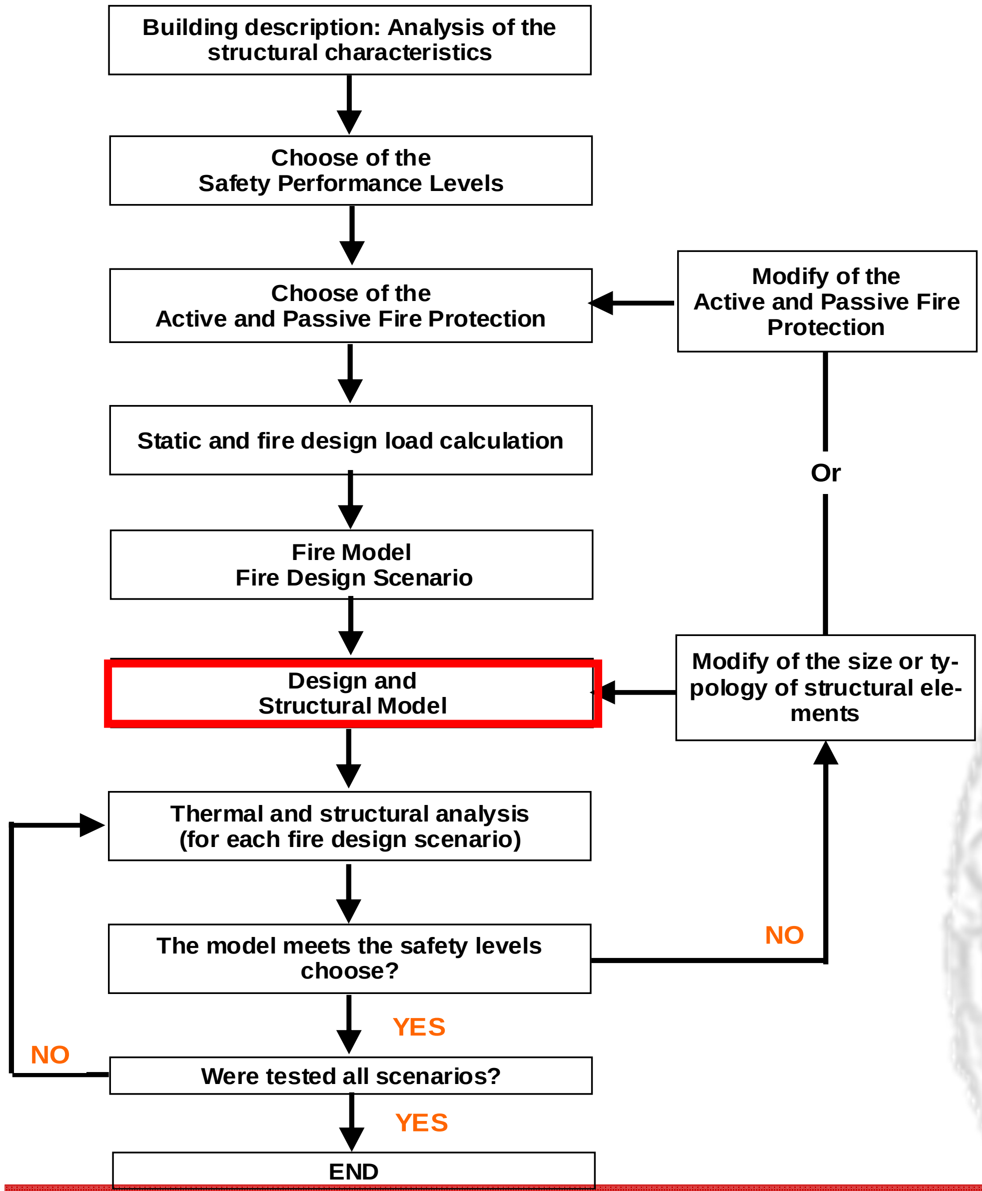
RHR curves



Heat Fluxes on structural members



Case Study: Car Parks of C.A.S.E. Project for L'Aquila



- **Global Structural Analyses**
- **Detailed 3D Structural Analyses**

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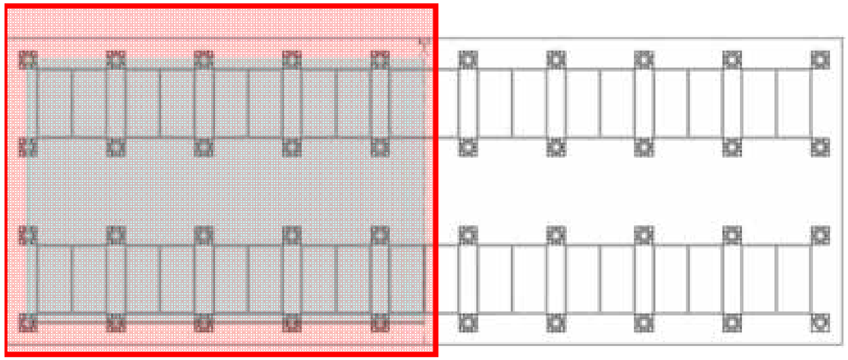
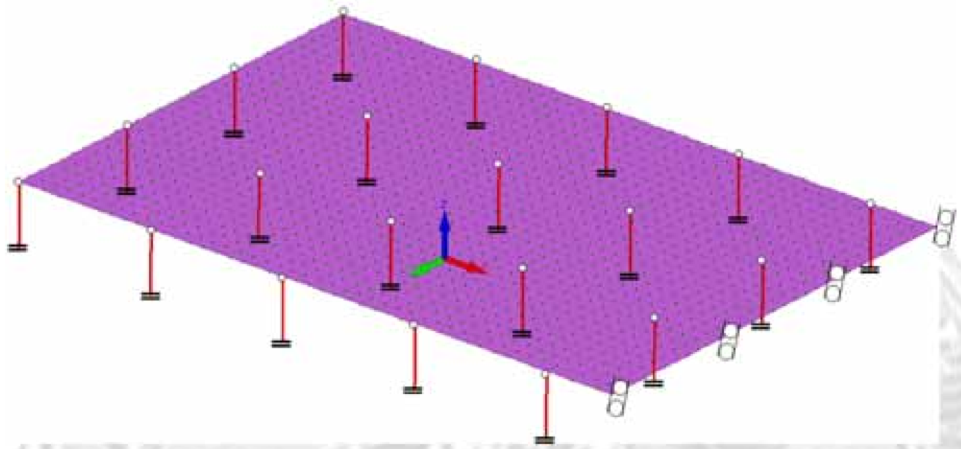
Case Study: Thermo-Mechanical Structural Analyses

✓ **Global Analyses** → **SAFIR 2007 (University of Liege, Belgium)**

In order to limit the analysis time without compromising the accuracy of the results, the thermo-mechanical analyses, for each fire scenario, have been conducted with the reference to a significant substructure.



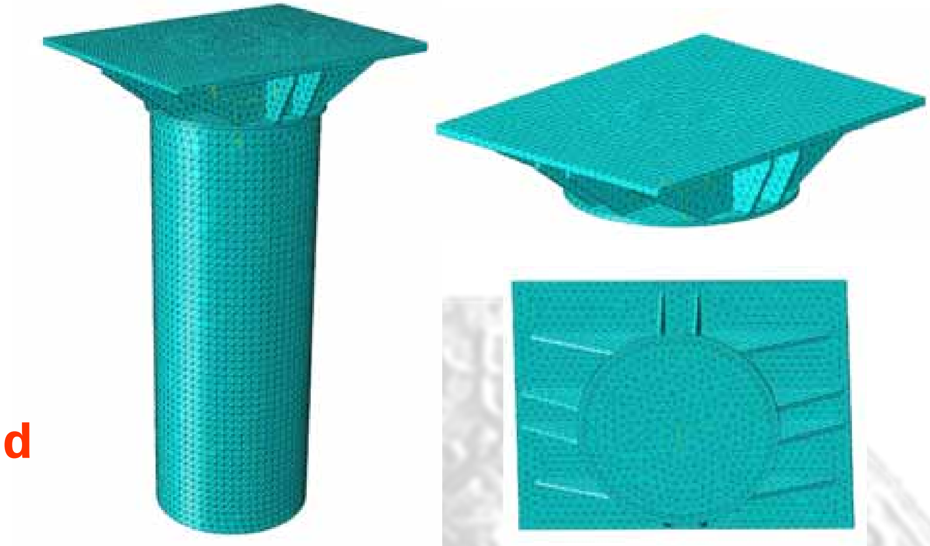


	Material	**Finite Element**	**Section**	**Thickness (mm)**
Columns	Steel S355	BEAM	Circular Hollow D_{ext} = 800mm	15
Slab	Concrete C30/37	SHELL	Solid	500

Case Study: Thermo-Mechanical Structural Analyses

✓ **Detailed 3D Analyses** → **ABAQUS**

in order to calculate more accurately the thermal field and stresses distribution in the capitals above the columns and to assess the possible local buckling.



Analyses have been conducted with reference to the more stressed and heated column

	Finite Element	Properties of finite element
Thermal Analyses	ABAQUS element DC3D4	4-node linear heat transfer tetrahedron
Mechanical Analyses	ABAQUS element C3D10	10-node quadratic tetrahedron

For each fire scenario, **the axial load at the top of column, corresponds to the axial load obtained by the global structural analyses.**

Case Study: Thermo-Mechanical Structural Analyses

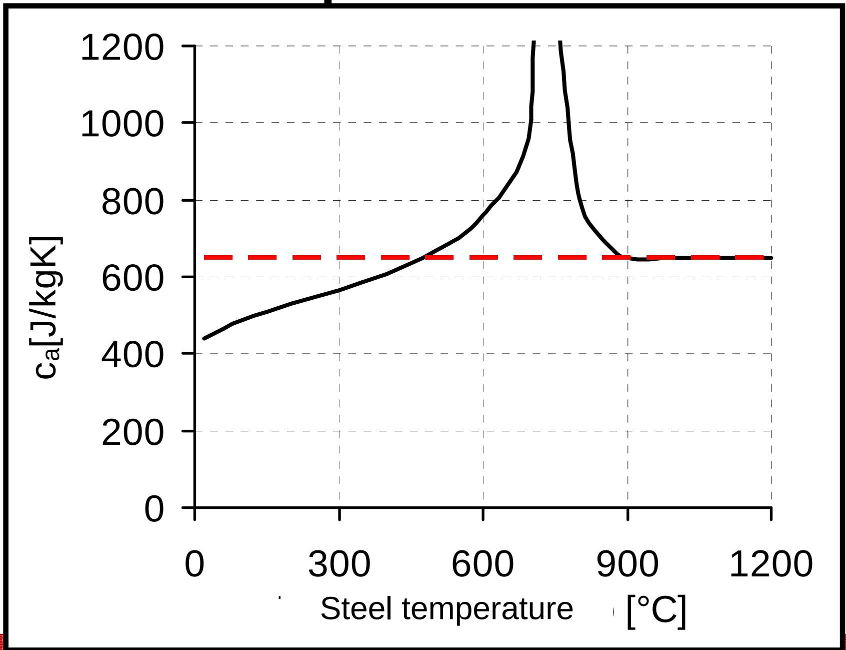
Thermal Analysis

Localized fire → **Boundary conditons: Heat flux**

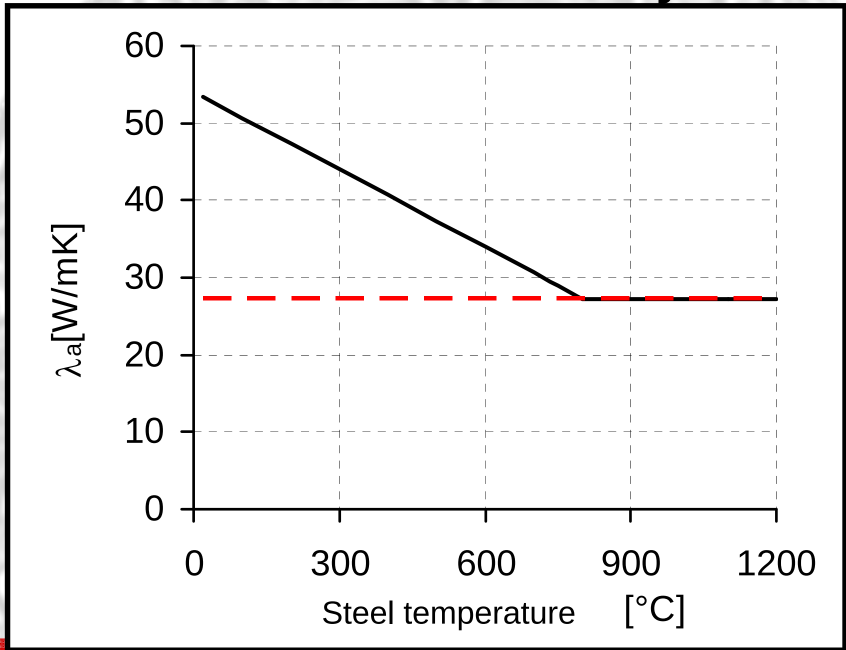
Generalized fire → **Boundary conditons: Temperature vs time curve**

Thermal properties of Steel (EN1993-1-2)

Specific heat



Thermal conductivity



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Mechanical Analysis

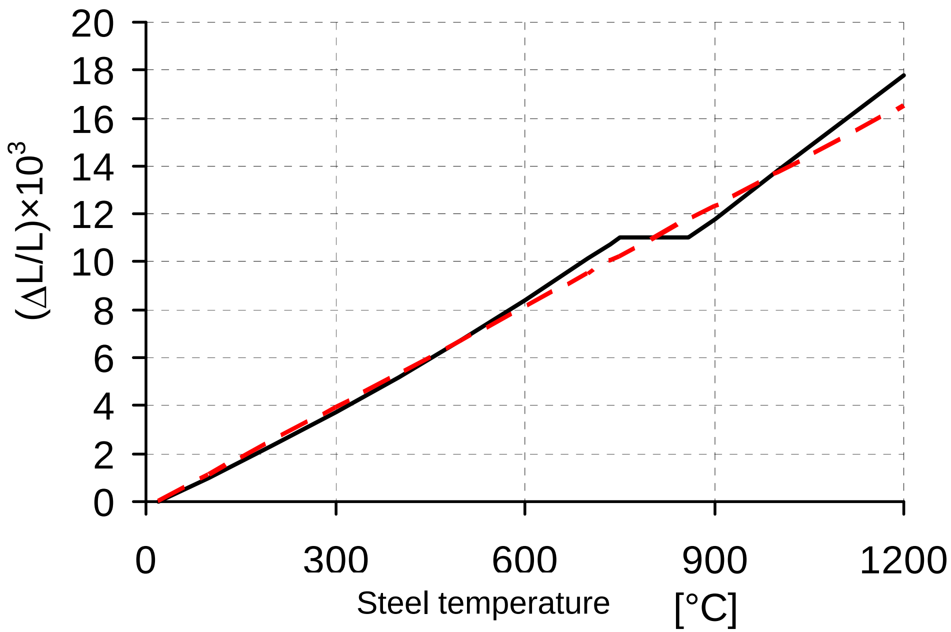
Localized fire

Generalized fire

→ **Boundary conditions: Thermal field obtained from Thermal Analysis**

Mechanical properties of Steel (EN1993-1-2)

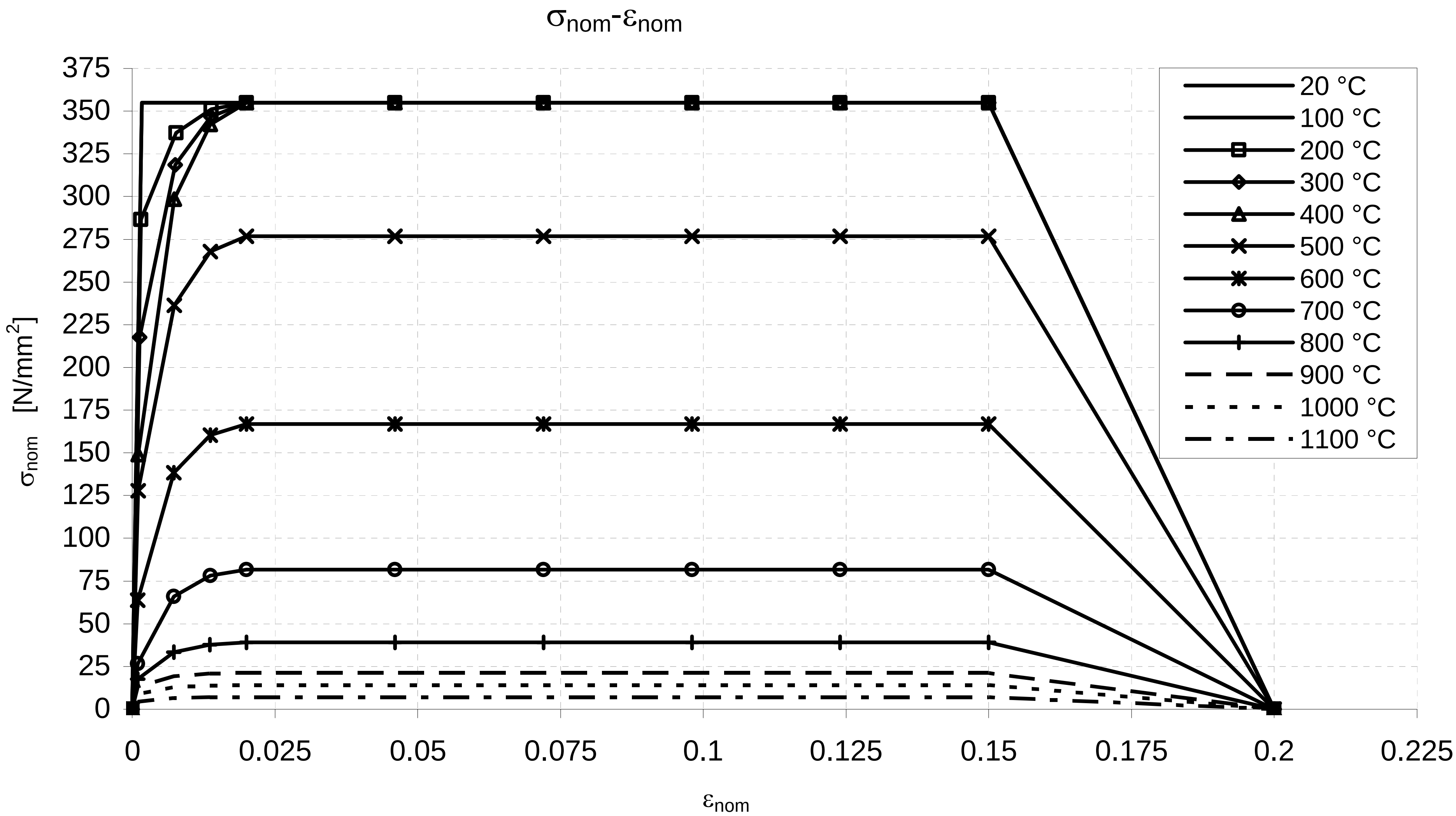
Thermal expansion



Strain-Stess Relationship

Case Study: Thermo-Mechanical Structural Analyses

Strain-Stess Relationship



Mechanical Analysis

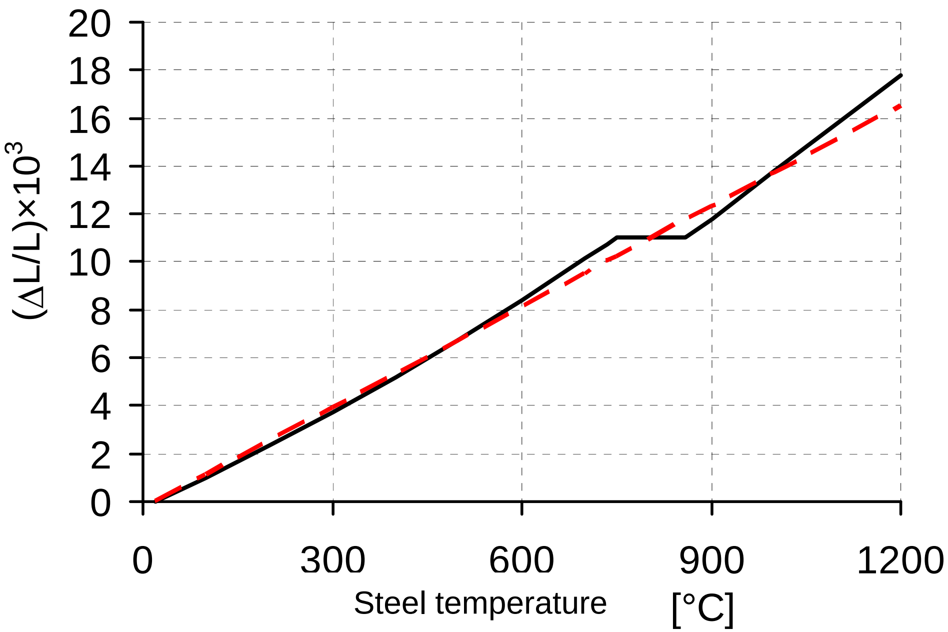
Localized fire

Generalized fire

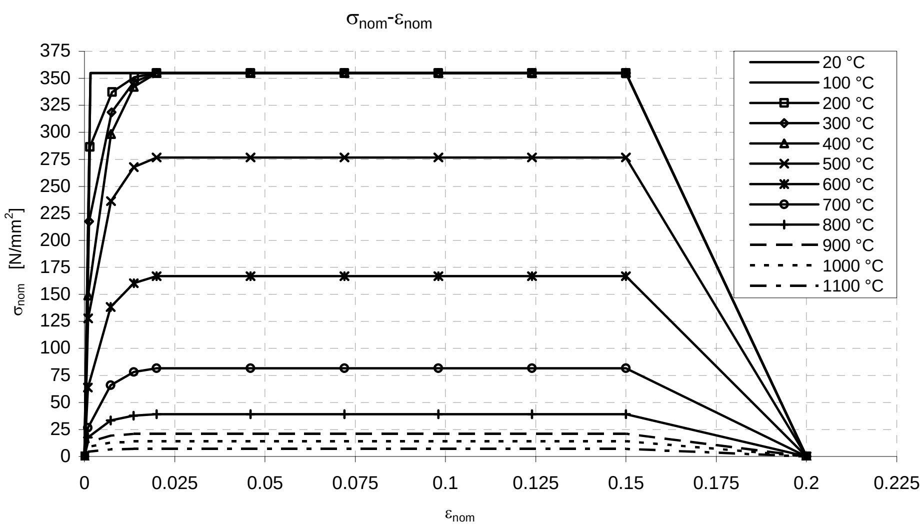
→ **Boundary conditions: Thermal field obtained from Thermal Analysis**

Mechanical properties of Steel (EN1993-1-2)

Thermal expansion



Strain-Stess Relationship



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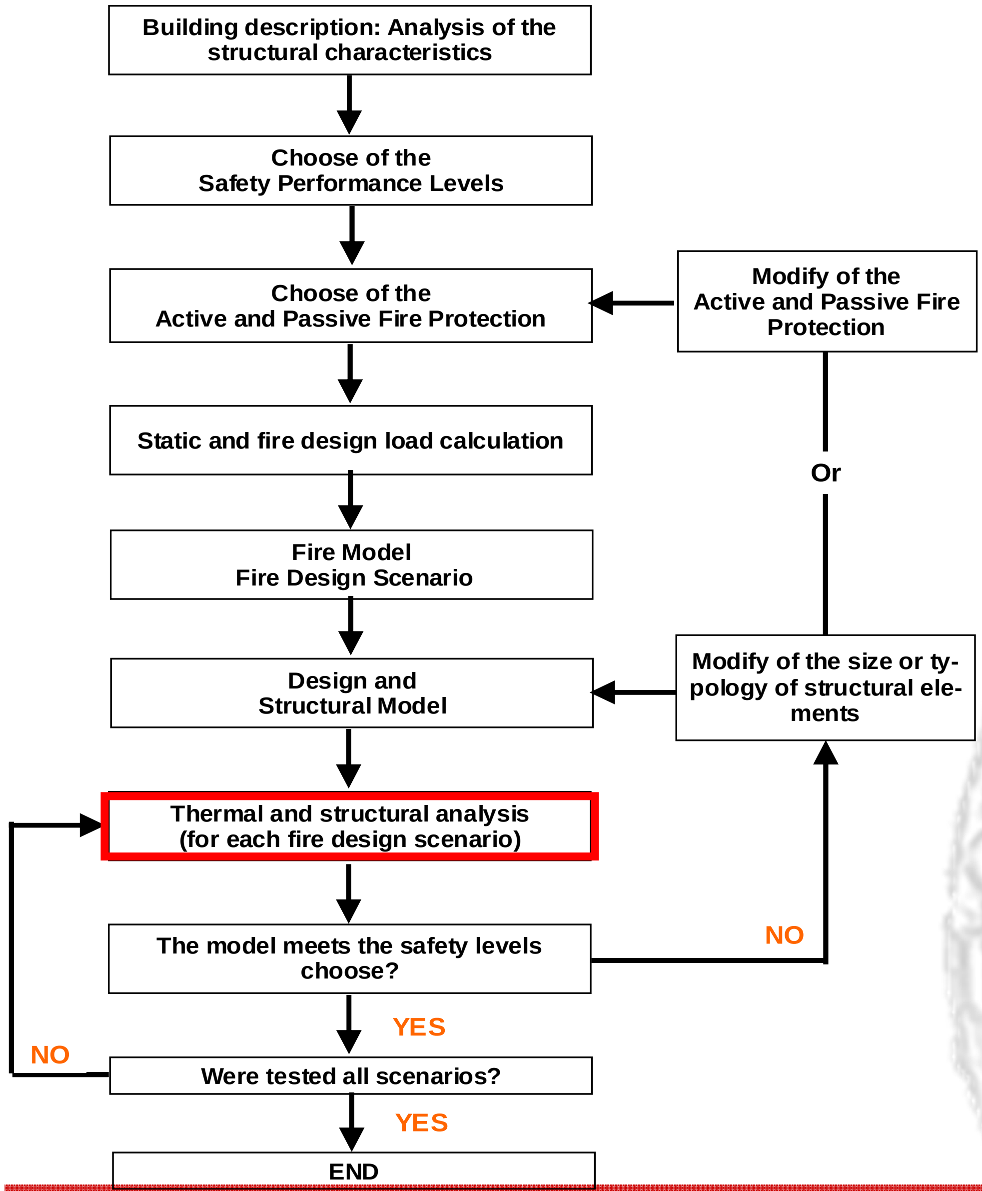
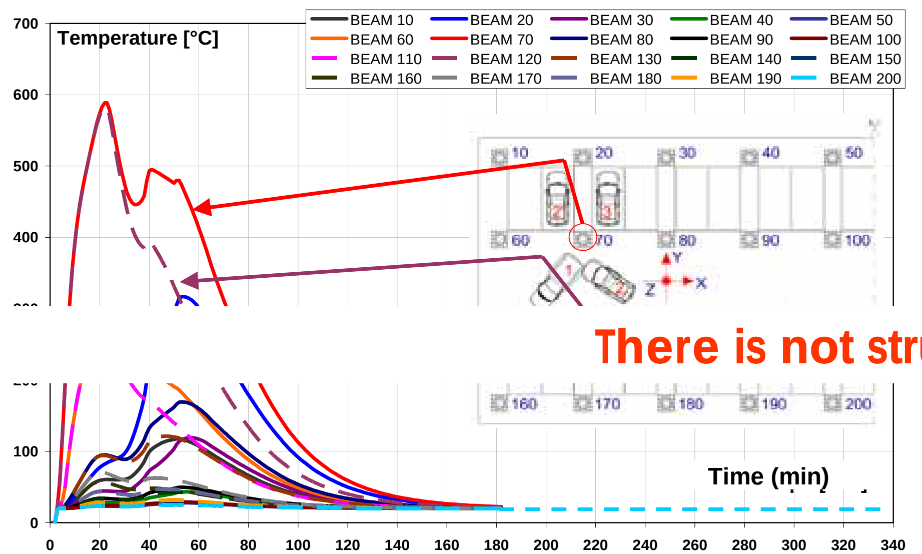
Case Study: Car Parks of C.A.S.E. Project for L'Aquila



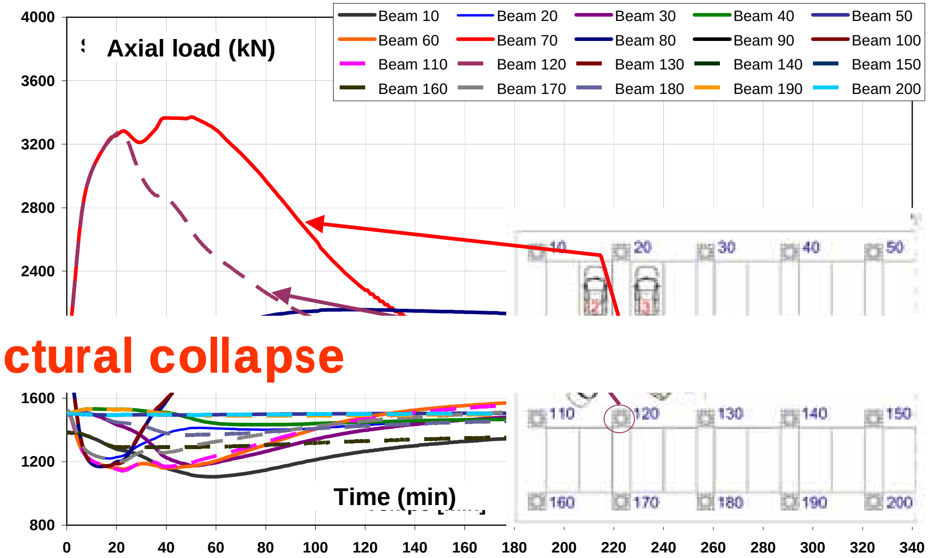
Case Study: Global Analyses Results

Fire scenario L2 – Global Analysis

Temperatures vs time

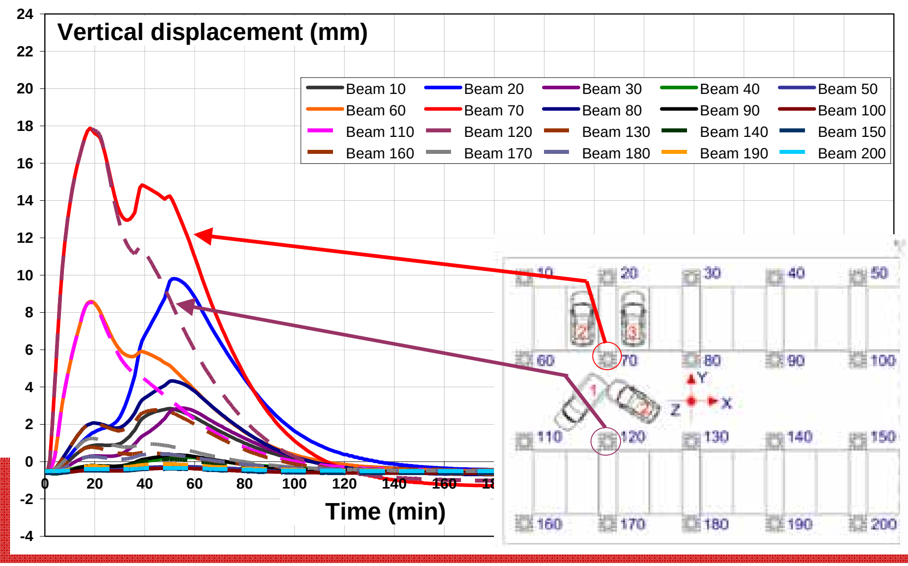


Axial loads vs time

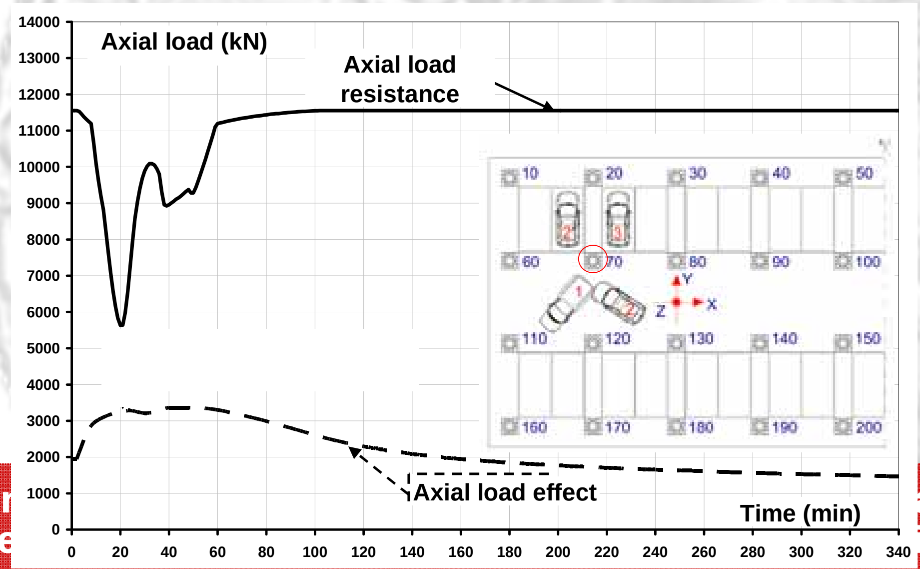


There is not structural collapse

Displacements vs time



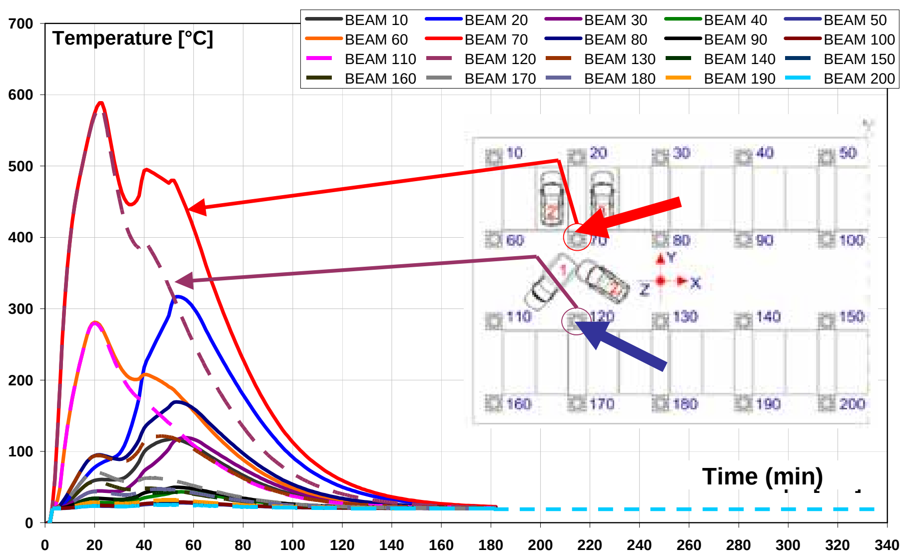
Axial load resistance vs time



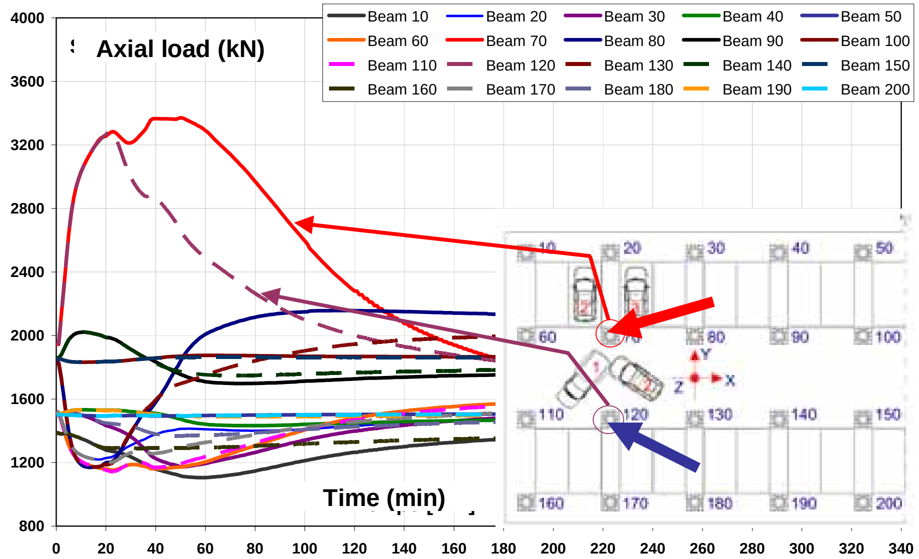
Case Study: Global Analyses Results

Fire scenario L2 – Global analysis

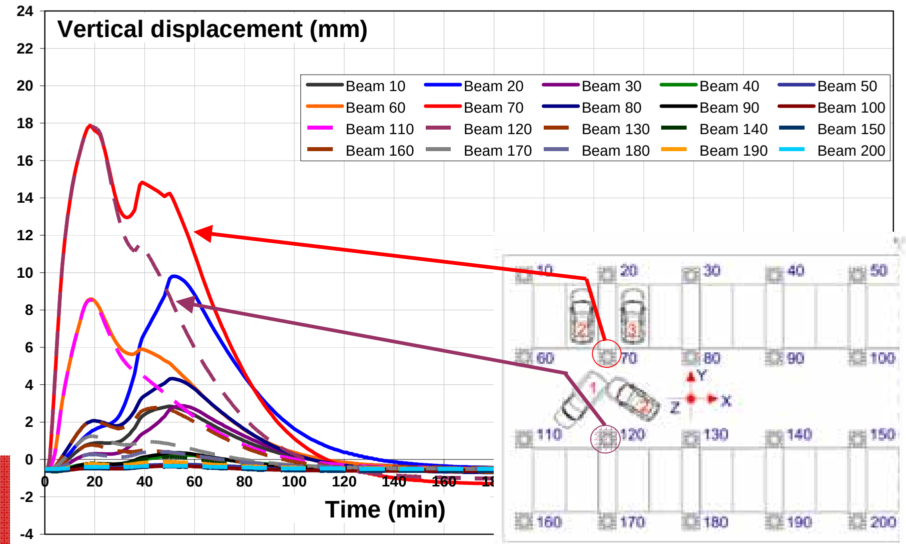
Temperatures vs time



Axial loads vs time



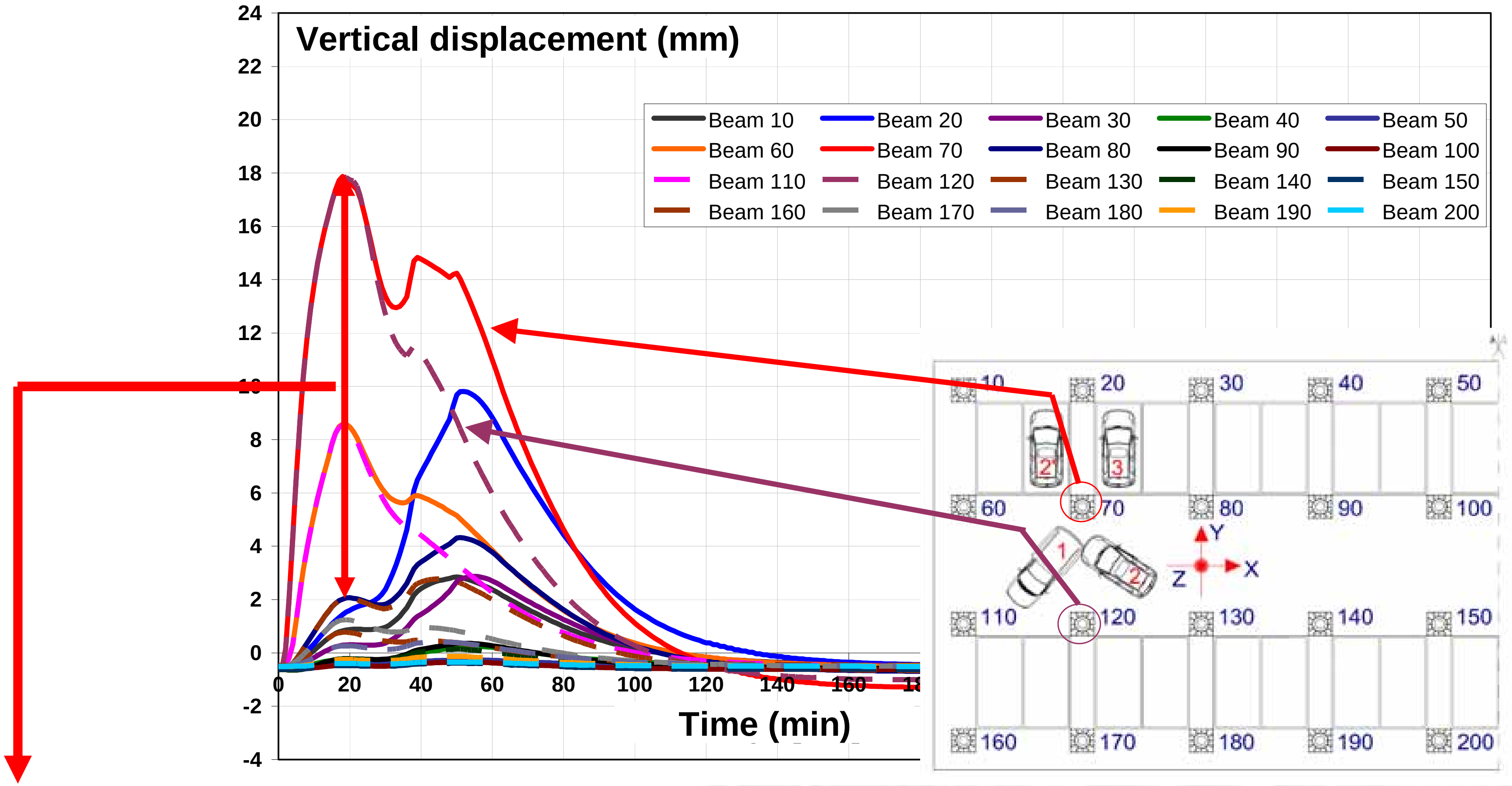
Displacements vs time



- The maximum temperatures reached in the columns do not exceed 600°C
- Because of the thermal curvature of the slab the axial load of these columns increase
- The axial load is further amplified from the differential thermal elongation of columns, exposed to different thermal conditions, which is constrained from slab shear stiffness
- The columns displacement reflects, in general, the temperatures trend.

Case Study: Global Analyses Results

Columns Displacements

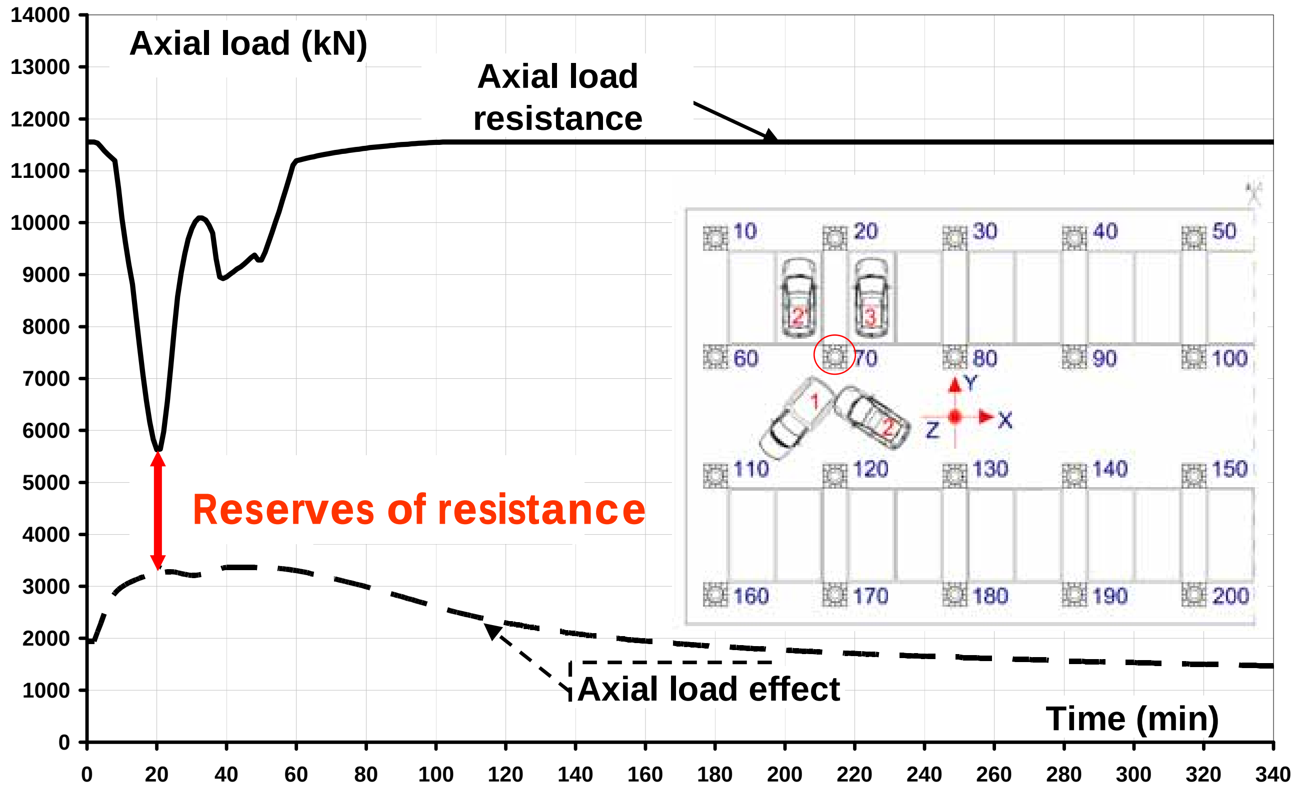


The **maximum differential displacement**, during the fire exposure, is about **16mm** (between the column 120 and column 130) and this value corresponds to **2.6 ‰** below the **limit value of 5.0 ‰**.

Case Study: Global Analyses Results

The axial load resistance of the column, evaluated according to EN1993-1-2, was compared with the axial load during the fire exposure.

Axial load resistance vs time



The more loaded column, even when the maximum temperature is reached, still has a significant reserves of resistance.

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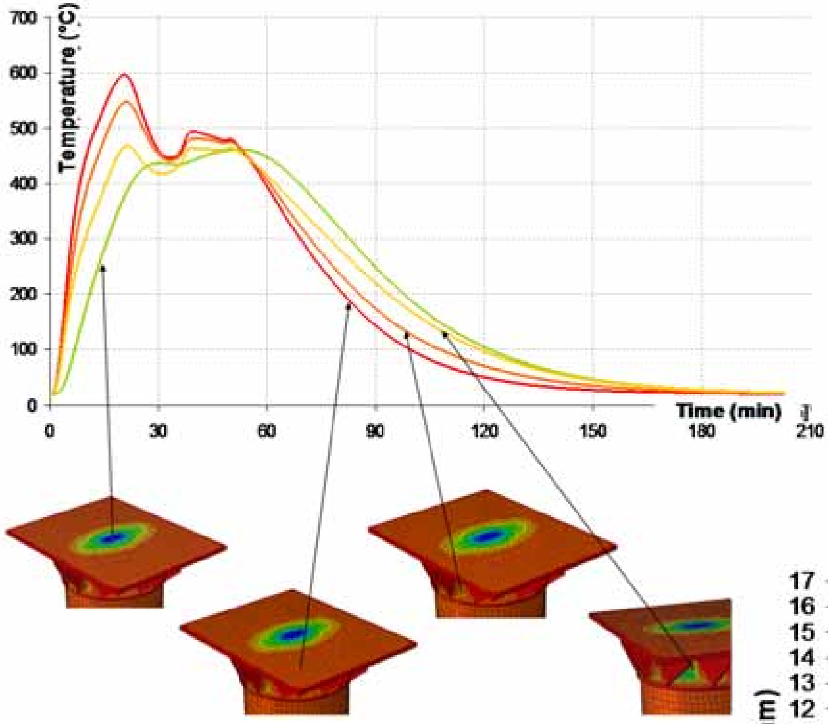
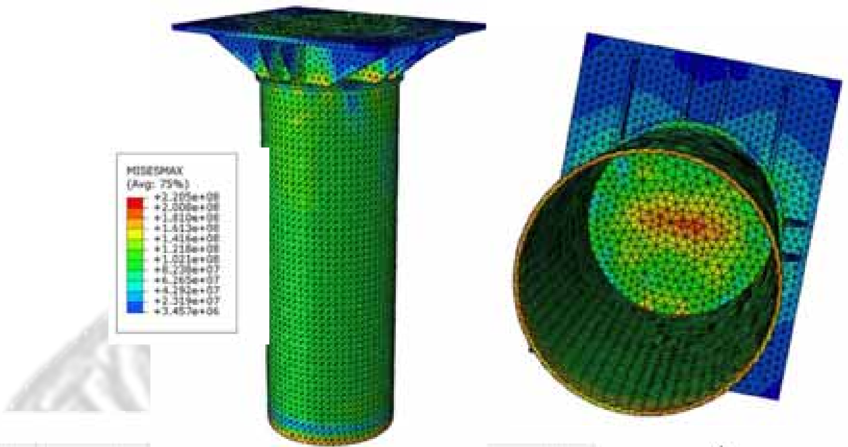
Case Study: Detailed Analyses Results

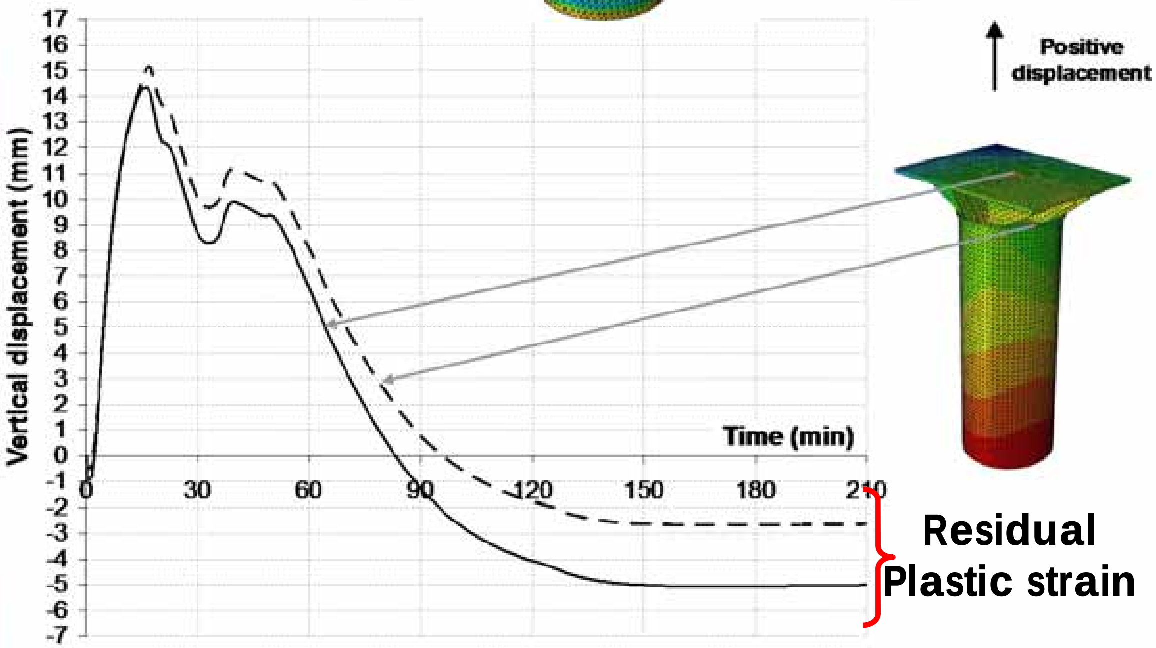
Fire scenario L2 – Detailed analysis



The 3D Thermal Analyses allowed to calculate more accurately the thermal field and stresses distribution in the capitals above the columns.



The displacement at the top of column is very similar to those obtained in the global structural analyses.
The final displacement is about 5mm in the central area of capital and about 2mm in the tube head: this is due to the plastic strain.



Conclusions

- ✓ The FSE application to car parks is facilitated by the information about the possible fire scenarios provided by the European Research Project CEC agreement 7215-PP/025 (2001) and from INERIS (2001) guideline.

- ✓ The substructure extension has allowed assessing in an appropriate way both the thermal field and the hyperstatic effects induced by different thermal expansions of steel columns and bending of the concrete reinforced slab.

- ✓ In addition to the global analysis, for each fire scenario, in order to calculate more accurately the thermal field and stresses distribution in the capitals above the columns and to assess the possible local buckling, detailed 3D thermo-mechanical analyses have been conducted with reference to the more stressed and heated column.

- ✓ The thermo-mechanical analyses in fire situations for the described case study showed that the structures, and in particular the steel columns, considered unprotected, satisfy the performance level set to the design fire scenarios, also thanks to an overstrength in normal condition design.

Future developments

- ✓ The fire development and its effects on the structure will be evaluated by software FDS in order to take into account the distribution of heat flux both along and around the columns.

Questions

- ✓ How to link CFD fire model and structural model?
  - ✓ Through Adiabatic Surface Temperature?
  - ✓ Which value of coefficient of heat transfer by convection should be assumed?
  - ✓ Which value of emissivity should be assumed?

Thank you for your attention

Thanks to:

Prof. E. Nigro
Prof. E. Cosenza
Prof. G. Manfredi
Eng. A. Ferraro